The Response of Wind Ripples to Long Surface Waves

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LONG-TERM GOAL

- To develop an advanced physical model of the wind wave spectrum based on the Donelan and Pierson (1987) approach and accounting for the nonlinear processes in the capillary-gravity range consistent with existing analytic models of high-wavenumber spectra.

- To construct a new version of the ABL model coupled with wind waves using an advanced wind wave spectrum model and the approach developed by Makin et al. (1995).

- To build an unified model of the short wave modulations by long surface waves. This model describes the reaction of the coupled system `wind waves - ABL' in the presence of surface disturbances caused by long waves.

- To verify the model results on the available radar data and the new data obtained from the MHI Black Sea Research platform.

APPROACH

The final shape of the wave spectrum is defined by competition of the coupling with the air boundary layer, wave-wave interaction (distributing energy and momentum across the spectrum), and dissipation through wave breaking and viscosity. The main objective of this study is to develop a unified physical model of the short wave modulation by a longer wave of an arbitrary origin taking into account the coupling of wind waves and the air boundary layer (ABL), wave-wave interaction and dissipation.

Recently a few `wind waves- ABL' coupled models have been proposed (e.g., Janssen, 1989; Chalikov and Makin, 1991; Makin et al., 1995). Kudryavtsev et al., (1997) have demonstrated that in such a coupled system a feed-back mechanism can emerge between the modulated wind waves and the near surface wind stress variations. This mechanism is responsible for the strong modulation of wind ripples by a long surface wave. A scheme of the feed-back action is the following: short waves affect the surface roughness, which determines the stress distribution. The stress in turn affects the short waves. The feed-back mechanism acts along with the wave-current and wave-wave interactions to produce the hydrodynamic modulation of wind ripples. In recent years the nonlinear interaction processes have been studied intensively; e.g. Zakharov (1992) and Pushkarev and Zakharov (1996).

The coupling between wind waves and the air flow is sensitive to the wave spectral form in the full wave-number range, in particular to the high wave-number part. At the same time, the active microwave sensor return depends on the short surface waves scattering through the Bragg resonance mechanism. Hence, an advanced physical model of the wind wave spectrum has to be constructed.

WORK COMPLETED

The structure of an advanced model of the wind-wave spectrum has been proposed, including advective processes, wind input, dissipation (both viscous and white-capping), effects of parasitism between short waves and somewhat longer waves, and nonlinear interactions. A meeting of the P.I.s, held at the MHI, Sevastopol in early June, provided a forum for detailed exchanges of ideas and calculations. The work continues with the individual P.I.s concentrating on parts of the problem.

Measurements of wind-wave interaction and wave development were made by members of the staff of MHI, under the guidance of Vladimir Kudryavtsev, on the Black Sea Research Tower in June, 1998.

RESULTS

Further refinement of the rate of wave amplification by wind has resulted from laboratory measurements (Donelan, 1998). Makin and Kudryavtsev (1998) have developed a coupled sea surface-atmosphere model. It consists of a wind over waves coupling model and a model of short wind waves. The approach of the wind over waves coupling is based on the conservation of momentum in the marine atmospheric surface boundary layer and allows to relate the sea drag to the properties of the sea surface. An assumption concerning the local balance of the turbulent kinetic energy production due to the mean and the wave-induced motions, and its dissipation allows to reduce the problem to two integral equations: the resistance law above waves and the coupling parameter. To calculate the wave-induced flux the local friction velocity rather than the total friction velocity is shown to be used. In this case the growth rate parameter depends on the coupling parameter. It is shown that the short gravity and capillary-gravity waves play a significant role in extracting momentum and are strongly coupled with the atmosphere. This fact dictates the use of the coupled short waves-atmosphere model in the description of the energy balance of those waves.

A physical model of the short wind wave spectrum in the wave length range from few millimetres to few meters is proposed. The spectrum shape results from the solution of the energy spectral density balance equation. In the capillary range the spectrum is determined by the mechanism of generation of parasitic capillaries. This is described as the cascade energy transfer from the gravity to the capillary waves. The capillary wave spectrum results through the balance between generation of capillaries and their viscous dissipation. The short gravity wave spectrum results through the balance between wind input and dissipation due to wave breaking. To obtain the short wave spectrum which is valid in the whole wavenumber domain the capillary and the short gravity wave spectra are patched in the vicinity of the wavenumber corresponding to the minimum phase velocity. This short wave spectrum is incorporated into the wind over waves coupled model.

The measured statistical properties of the sea surface related to the short waves, such as the spectral shape of omni-directional and up-wind spectra, their energy level wind speed dependence, angular spreading, and the wind speed dependence of integral mean square slope and skewness parameters, are well reproduced by the coupled sea surface- atmosphere model. The model reproduces as well the measured wind speed dependence of the drag coefficient and of the coupling parameter.

Calculations of the nonlinear interactions in the capillary-gravity range have been extended by Pushkarev and Zakharov (1998). It was shown by direct numerical simulation of dynamical equations that stationary spectra of capillary waves obey the Kolmogorov law $K^{-19/4}$, which is exact solution of kinetic equation for waves. In the situation when the turbulence is realized in a finite-size tank there is a completely new effect of "frozen turbulence" which could be realized at very low levels of the excitations of capillary waves. At the "frozen turbulence" regime there is no energy flux from low wavenumbers of pumping toward high wavenumbers of damping.

The field tower measurements using wave following devices, optical slope gauges and X-band and Ka-band radars (the former was done in collaboration with the Institute of Applied Physics, Russia) have helped improve our understanding of the sensitivity and rapidity of response of capillary-gravity waves to wind forcing, dissipation, wave-wave interaction and modulation by longer waves.

IMPACT/APPLICATION

The impact of this work will be most immediately felt in the radar remote sensing community, where a complete model of the capillary-gravity waves, founded on sound physical principles and verified against field and laboratory data, is sorely needed. Other applications are in understanding and parameterizing such critical air-sea exchanges as gas transfer, momentum and heat transfer.

TRANSITIONS

None yet.

RELATED PROJECTS

The new Air-Sea Interaction Salt-water Tank (ASIST) facility, to be built on the campus of the Rosenstiel School of the University of Miami, will have the necessary delicate measuring capability to benefit from and further test the model being developed here.

REFERENCES

Chalikov, D. and V. Makin, 1991: Modes of the wave boundary layer. *Bound. Layer Meteor.*, **63**, 65-96.

Donelan M.A. and W.J., Pierson, 1987: Radar scattering and equilibrium ranges in wind-generated waves with applications to scatterometry. *J. Geophys. Res.*, **92**, 4971-5029.

Donelan, M.A., 1998: Wind-induced growth and attenuation of laboratory waves. Proc. IMA Conf. *On Wind-Over-Wave Couplings: Perspectives and Prospects*. Salford, UK., in press.

Janssen P.A.E.M., 1989: Wave-induced stress and the drag of air flow over sea waves. J. Phys. Oceanogr., **19**, 19,745-19,754.

Kudryavtsev, V.N., Mastenbroek, C. and Makin, V.K., 1997: Modulation of wind ripples by long surface waves via the air flow: a feed-back mechanism. *Bound. Layer Meteor.*, **83**, 99-116.

Kudryavtsev, V.N., V.K. Makin and B. Chapron: 1998: Coupled sea surface-atmosphere model. Part 2. Spectrum of short wind waves. *J. Geophys. Res.*, in press.

Makin, V.K., Kudryavtsev, V.N. and Mastenbroek, C. 1995: Drag of the sea surface. *Bound. Layer Meteor.*, 73, 159-182.

Makin, V.K. and V.N. Kudryavtsev, 1998: Coupled sea surface-atmosphere model. Part 1. Wind over waves coupling. *J. Geophys. Res.*, in press.

Pushkarev, A.N. and Zakharov, V.E., 1996: Turbulence of capillary waves. *Phys. Rev. Let.*, **76**, 3320-3323.

Pushkarev, A.N. and Zakharov, V.E., 1998: Turbulence of capillary waves – Theory and numerical simulations. *Physica D.* in press.

Zakharov, V.E., 1992: Inverse and direct cascade in wind-driven surface turbulence and wave-breaking. *Proc. IUTAM Symp. on Wave Breaking*. M.L. Banner and R.N.J. Grimshaw (Eds.), Springer-Verlag, . 69-91.

PUBLICATIONS

Donelan, M.A., 1998: Wind-induced growth and attenuation of laboratory waves. Proc. IMA Conf. *On Wind-Over-Wave Couplings: Perspectives and Prospects*. Salford, UK., in press.

Kudryavtsev, V.N., V.K. Makin and B. Chapron: 1998: Coupled sea surface-atmosphere model. Part 2. Spectrum of short wind waves. *J. Geophys. Res.*, in press.

Makin, V.K. and V.N. Kudryavtsev, 1998: Coupled sea surface-atmosphere model. Part 1. Wind over waves coupling. *J. Geophys. Res.*, in press.

Pushkarev, A.N. and Zakharov, V.E., 1998: Turbulence of capillary waves – Theory and numerical simulations. *Physica D.* in press.